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# "Two-Microphone" Nearfield Acoustical Holography

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Bolton, J Stuart; Cho, Yong T.; Kwon, Hyu-Sang; and Kim, Yong-Joe, ""Two-Microphone" Nearfield Acoustical Holography" (2005).  
*Publications of the Ray W. Herrick Laboratories*. Paper 49.  
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# **“TWO-MICROPHONE” NEARFIELD ACOUSTICAL HOLOGRAPHY**

**Yong T. Cho and J. Stuart Bolton  
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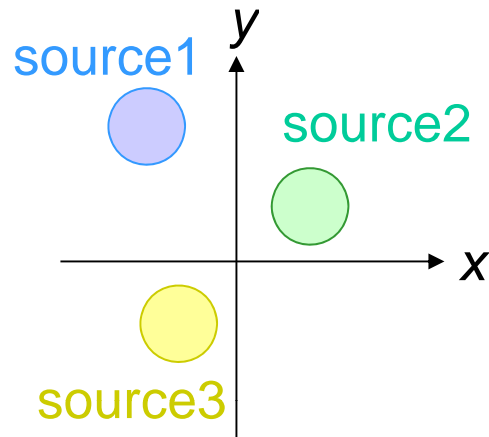


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# INTRODUCTION

- **Conventional NAH**
  - Measurement time required for complete measurement enclosing the acoustic source may be formidable especially when the size of source is large and sound field radiated in various operating conditions is of interest.
- **Two-microphone Nearfield Acoustical Holography**
  - Only one complete measurement enclosing the acoustic source is required to estimate the sound field of acoustic source for various operating conditions.

# PARTIAL FIELD DECOMPOSITION

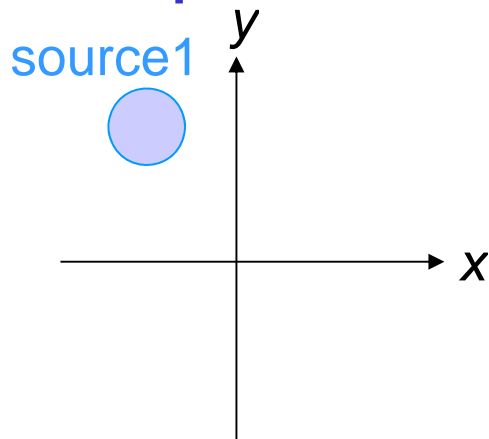


**Total sound field**

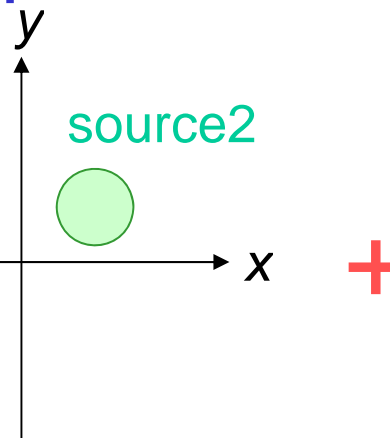
**Consist of three incoherent sources**

**Can be decomposed to three partial fields**

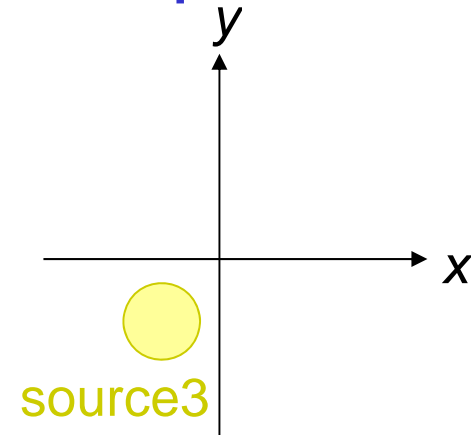
**First partial field**



**Second partial field**

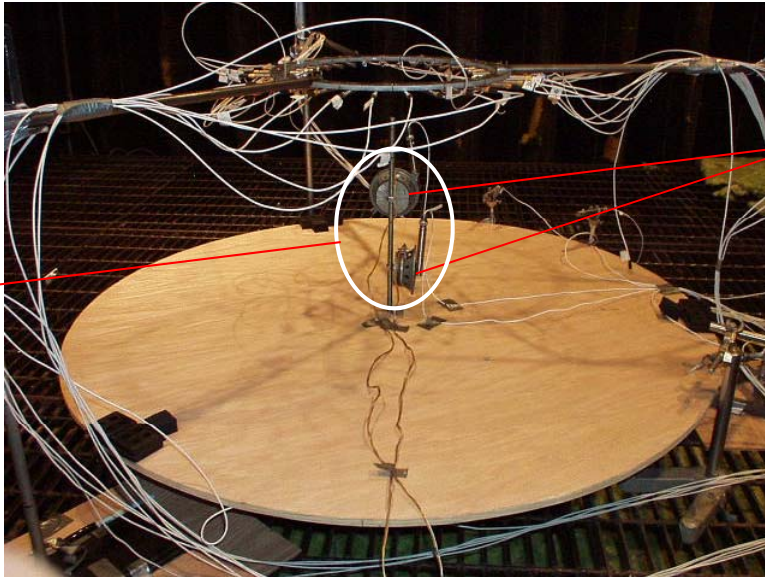


**Third partial field**



# OBJECTIVE

- Facilitate sound field measurement of the same composite acoustic source in various operating conditions.



“Source”

- Two independent sub-sources comprise complete source.
- Relative levels of sub-sources depend on operating condition.

- Reduce cost of acoustic measurement and allow more detailed investigation of acoustic sources in various operating conditions.

# TWO-MICROPHONE HOLOGRAPHY

- **Key assumption**

Transfer function between reference and field microphones is assumed to be remain identical for various combinations of source level or operating conditions – true if directivity of sub-sources is independent of level.

- **Benefit**

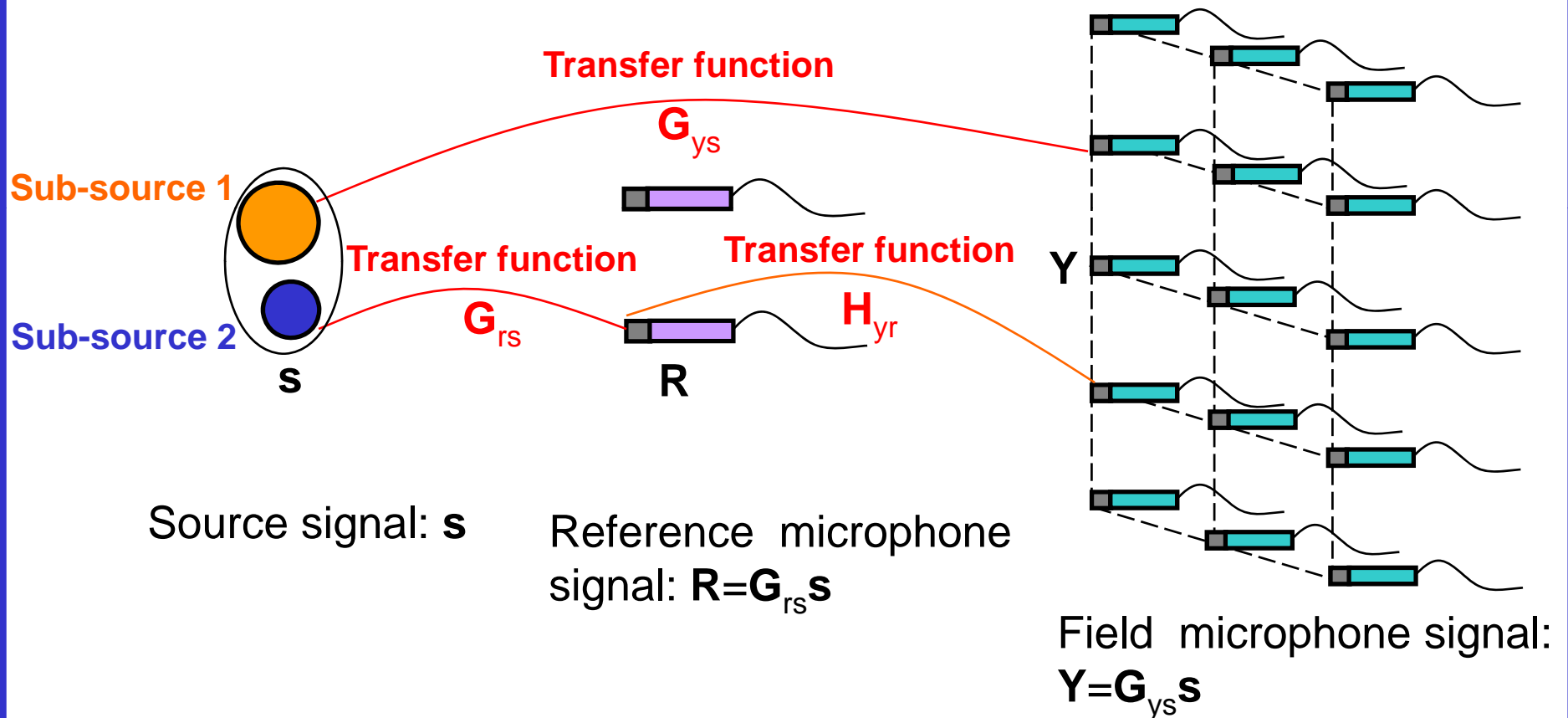
Partial fields for different operating conditions can then be estimated from a measurement of the reference spectral matrix alone.

# TWO-MICROPHONE HOLOGRAPHY

Sound sources

Reference microphones

Field microphones



# TWO-MICROPHONE HOLOGRAPHY

$$\mathbf{R} = \mathbf{G}_{rs} \mathbf{s},$$

$$\mathbf{Y} = \mathbf{G}_{ys} \mathbf{s},$$

$$\mathbf{S}_{ry} = E\{\mathbf{R}\mathbf{Y}^H\} = \mathbf{G}_{rs} \mathbf{S}_{ss} \mathbf{G}_{ys}^H \quad \text{or} \quad \mathbf{S}_{ry}^H = \mathbf{G}_{ys} \mathbf{S}_{ss} \mathbf{G}_{rs}^H,$$

$$\mathbf{S}_{rr} = E\{\mathbf{R}\mathbf{R}^H\} = \mathbf{G}_{rs} \mathbf{S}_{ss} \mathbf{G}_{rs}^H,$$

**Transfer function** between **reference** and **field** microphones:

$$\mathbf{H}_{yr} = \mathbf{Y}\mathbf{R}^{-1} = \mathbf{G}_{ys} \mathbf{G}_{rs}^{-1} = \mathbf{S}_{ry}^H \mathbf{S}_{rr}^{-1}$$

is independent of sub-source level combination (i.e., operating condition), so long as directivity of component sub-sources is independent of level.



# TWO-MICROPHONE HOLOGRAPHY

$$\begin{aligned} \mathbf{S}_{yy} &= \mathbf{E}\{\mathbf{Y}\mathbf{Y}^H\} = \mathbf{G}_{ys} \mathbf{S}_{ss} \mathbf{G}_{ys}^H = \mathbf{H}_{yr} \mathbf{G}_{rs} \mathbf{S}_{ss} \mathbf{G}_{ys}^H = \mathbf{H}_{yr} \mathbf{S}_{ry} \\ &= \mathbf{S}_{ry}^H \mathbf{S}_{rr}^{-1} \mathbf{S}_{ry} = \mathbf{P} \mathbf{P}^H \end{aligned}$$

Hence the partial field matrix,  $\mathbf{P}$ , is,

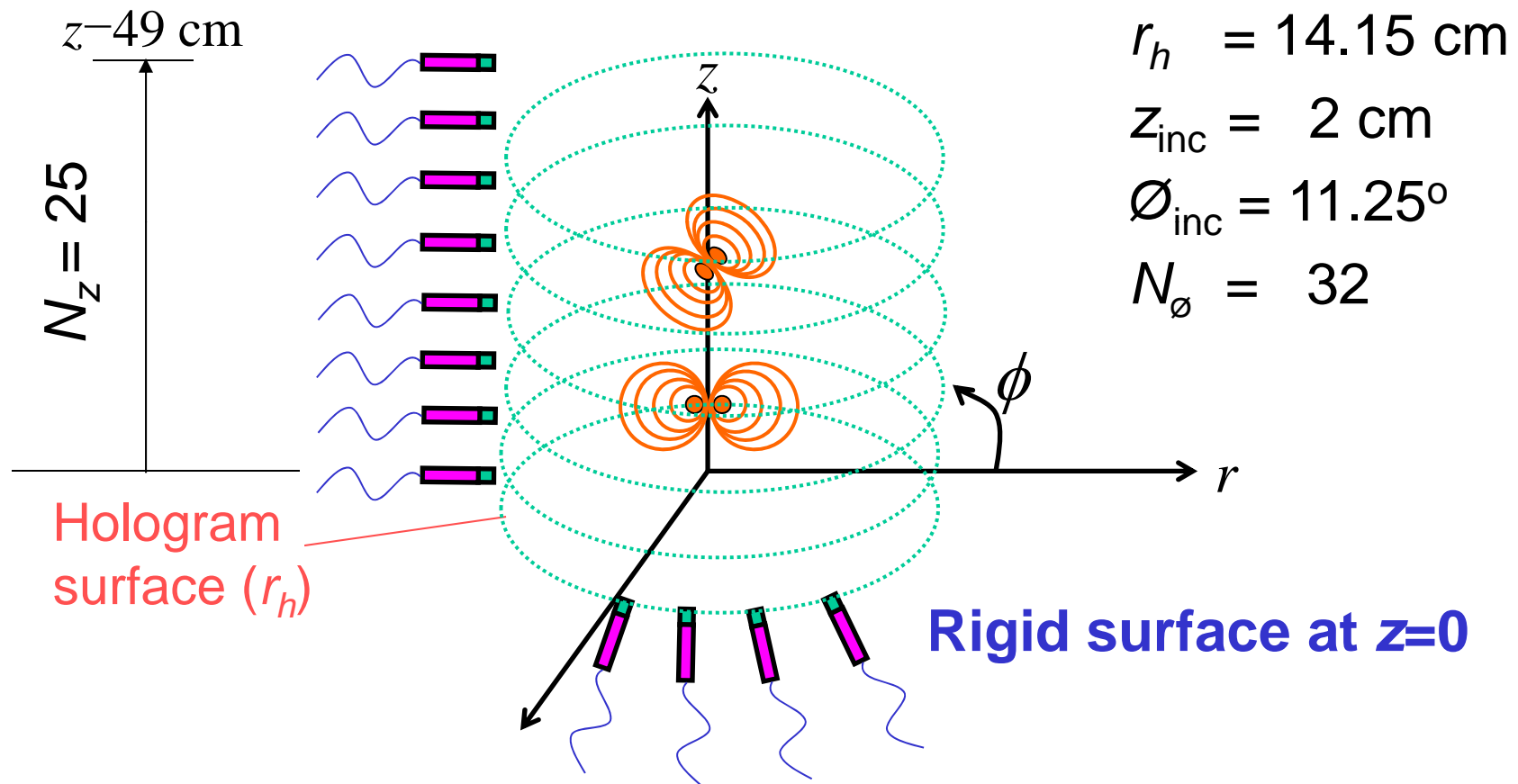
$$\mathbf{P} = \mathbf{S}_{ry}^H \mathbf{S}_{rr}^{-1/2} = \mathbf{H}_{yr} \mathbf{S}_{rr}^{1/2}$$

Partial fields for the  $n$ th operating condition can then be estimated from a measurement of the  $n$ th reference spectral matrix  $\mathbf{S}_{rr,n}$  alone when  $\mathbf{H}_{yr}$  is known from measurement in  $m$ th operating condition: i.e.,

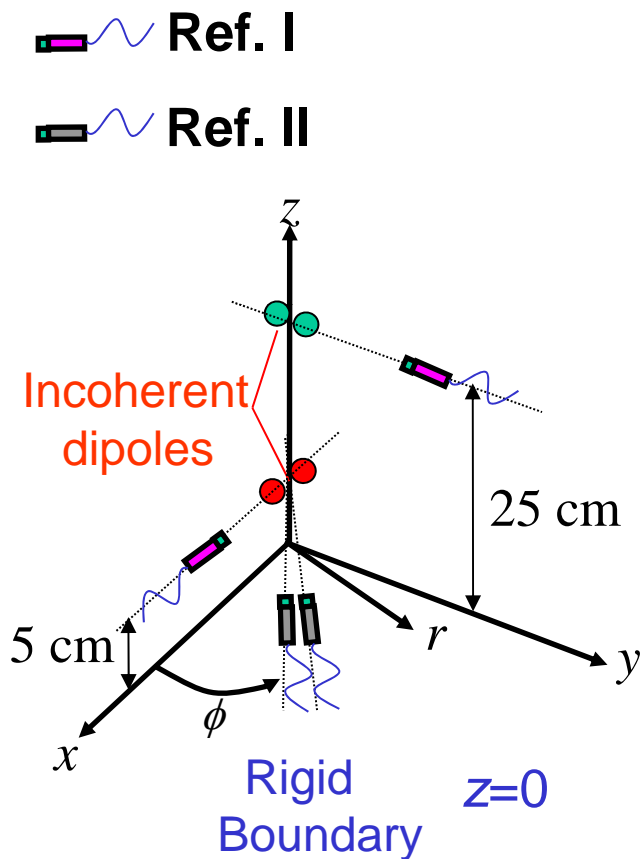
$$\mathbf{P}_n = \mathbf{H}_{yr,n} \mathbf{S}_{rr,n}^{1/2} = \mathbf{H}_{yr} \mathbf{S}_{rr,n}^{1/2}$$

# DIPOLE NUMERICAL SIMULATION

- Dipole axes in  $\phi=0$ ,  $z=5$  cm and  $\phi=90^\circ$ ,  $z=25$  cm



# DIPOLE NUMERICAL SIMULATION

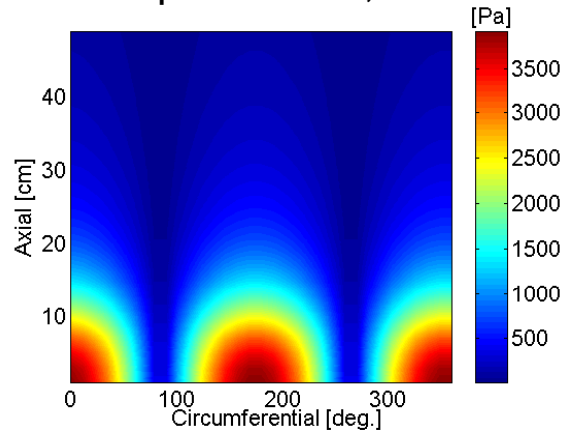


Cases		Source Amplitude		Ref. Mic. Position ( $r=10$ cm)			
		A	B	$\theta_1$ (deg)	$z_1$ (cm)	$\theta_2$ (deg)	$z_2$ (cm)
Ref. I	Level I	1	1	0	5	90	25
	Level II	0.5	1.5				
Ref. II	Level I	1	1	40	5	50	5
	Level II	0.5	1.5				

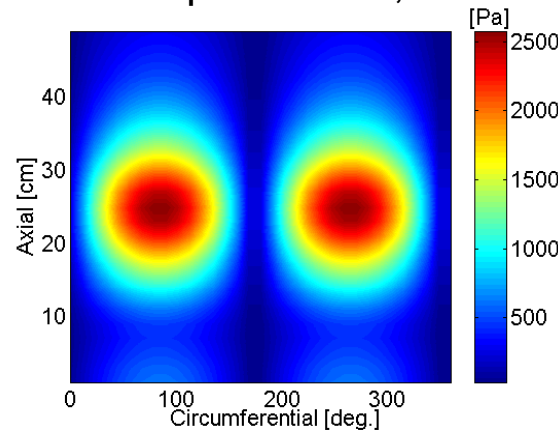
# DIPOLE NUMERICAL SIMULATION

## Sound fields from direct measurement (1000 Hz)

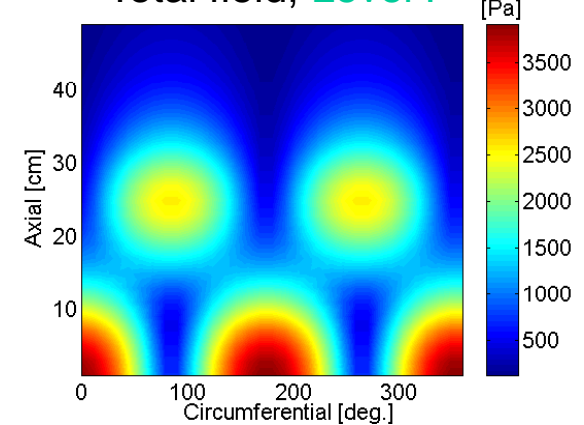
First partial field, Level I



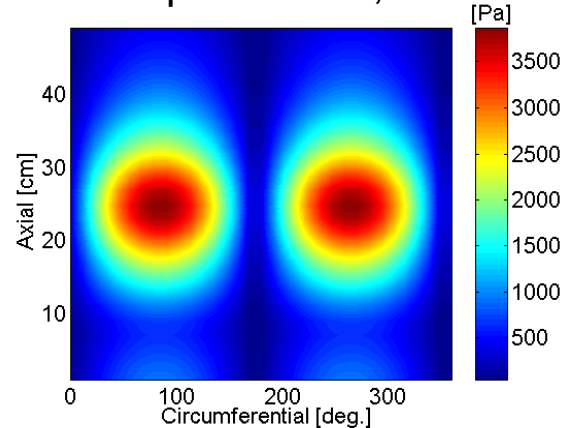
Second partial field, Level I



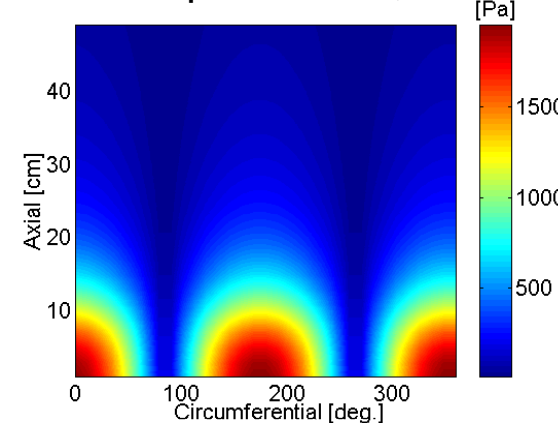
Total field, Level I



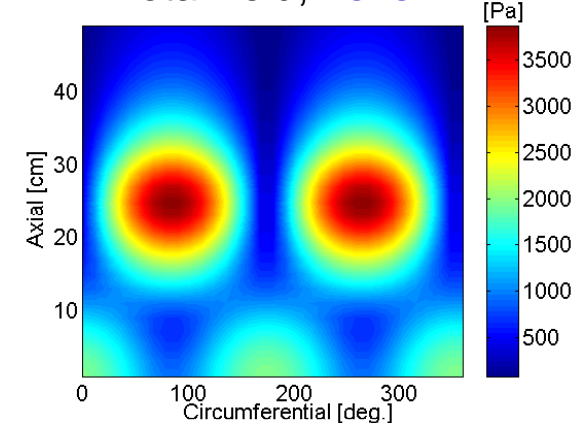
First partial field, Level II



Second partial field, Level II



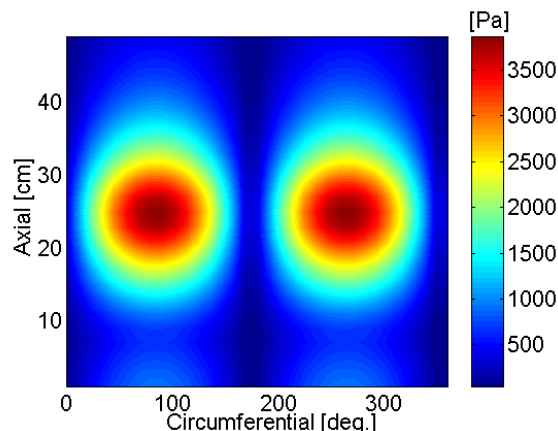
Total field, Level II



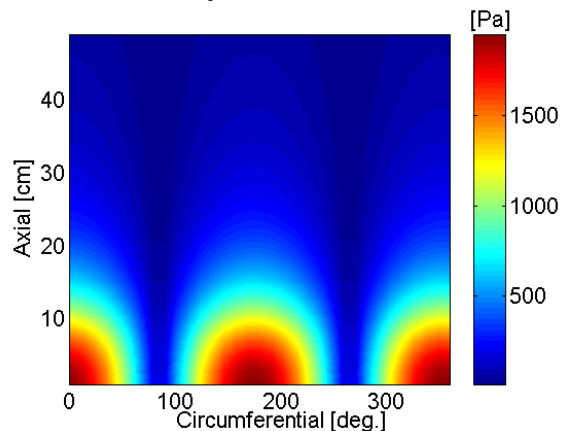
# DIPOLE NUMERICAL SIMULATION

Estimated sound fields for source level II (based on source level I  $H_{yr}$ )

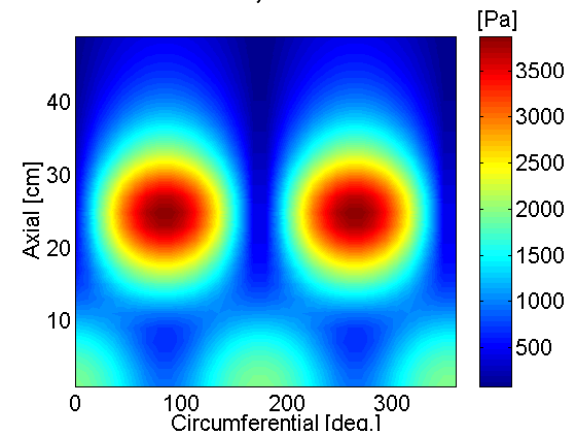
First partial field, Ref. I



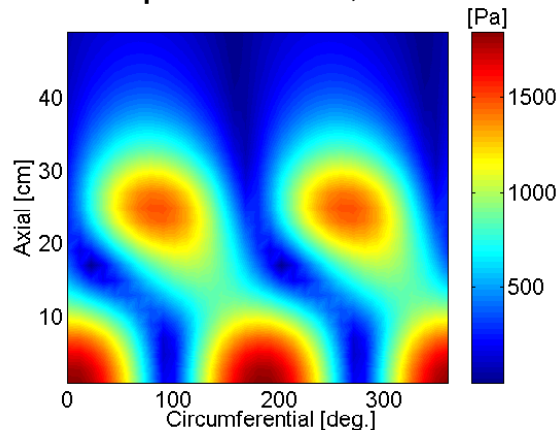
Second partial field, Ref. I



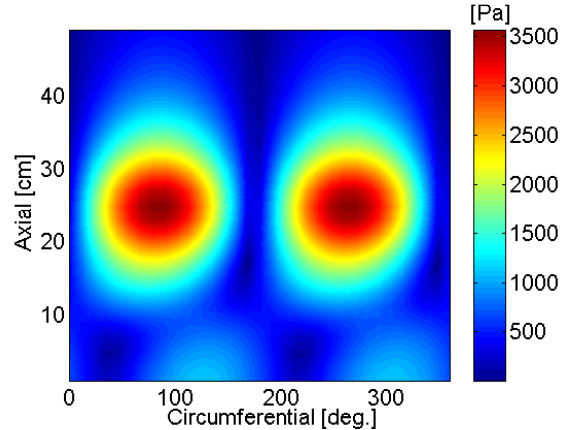
Total field, Ref. I



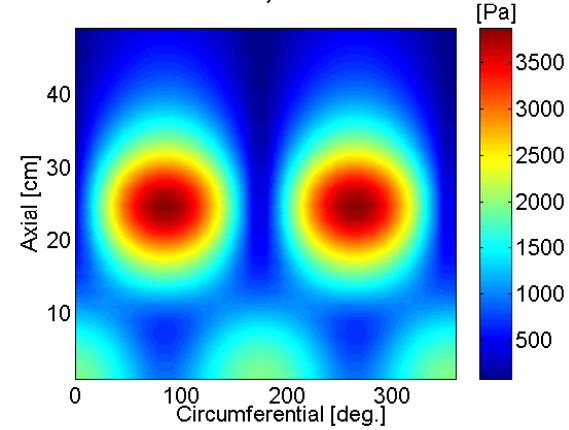
First partial field, Ref. II



Second partial field, Ref. II



Total field, Ref. II

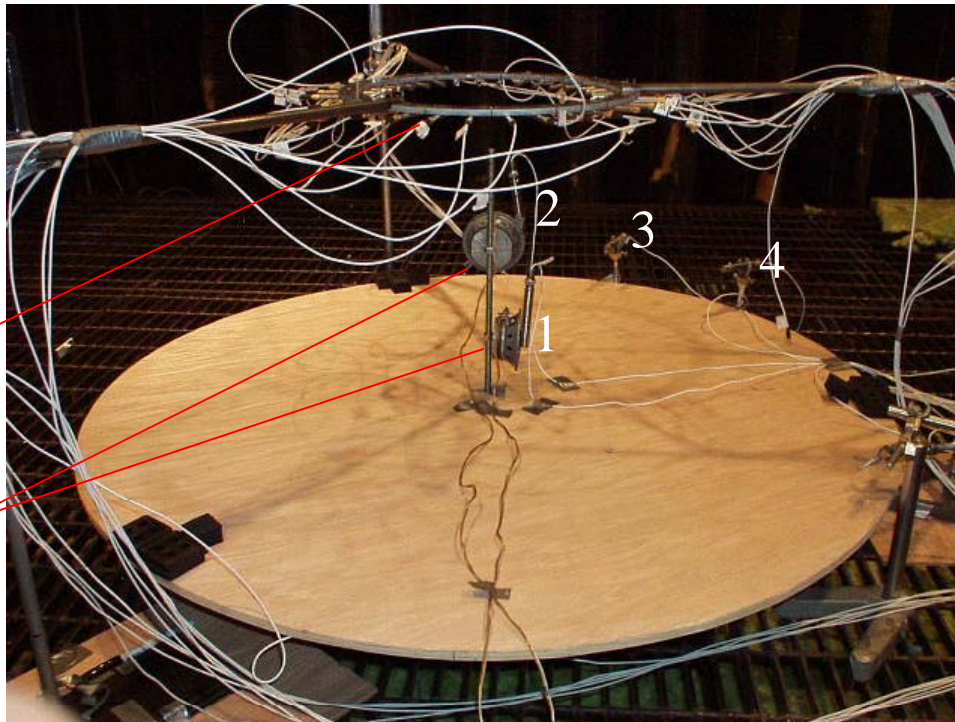


# LOUDSPEAKER MEASUREMENT

- Number of field microphones :  $N_{\emptyset} = 32$  ( $\emptyset_{inc} = 11.25^\circ$ )
- Microphone spacing in z direction :  $z_{inc} = 2.5$  cm
- Radius of hologram :  $r_h = 13$  cm
- Total aperture size : 42.5 cm ( $N_z = 17$ )
- Total number of measurement : 544

Scanning  
array

Unbaffled  
loudspeakers

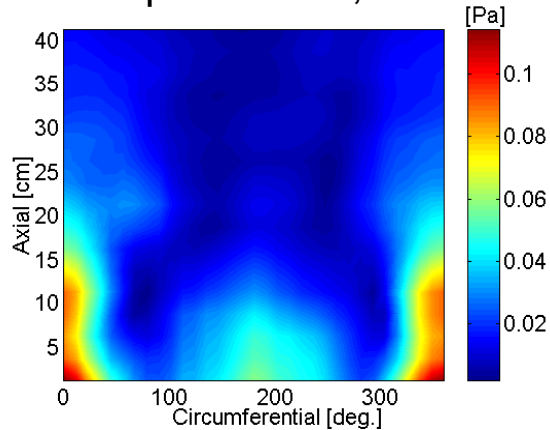




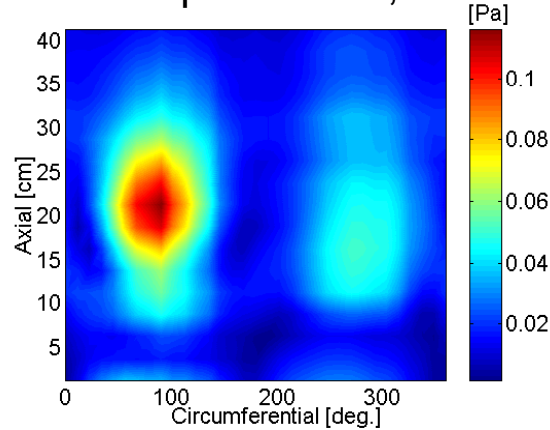
# LOUDSPEAKER MEASUREMENT

Sound fields from direct measurement, reference 1 and 2 (2000 Hz)

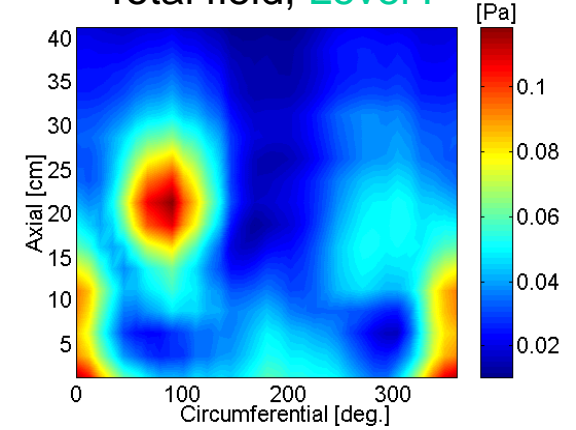
First partial field, Level I



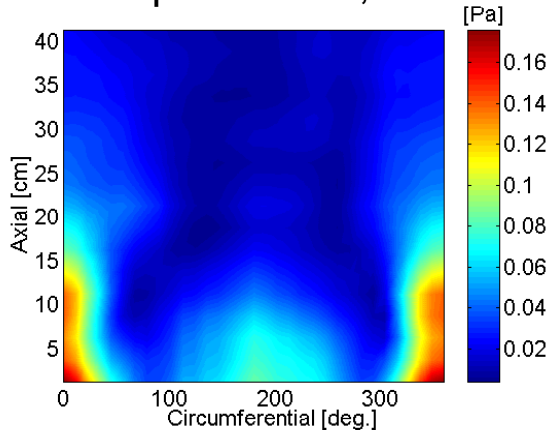
Second partial field, Level I



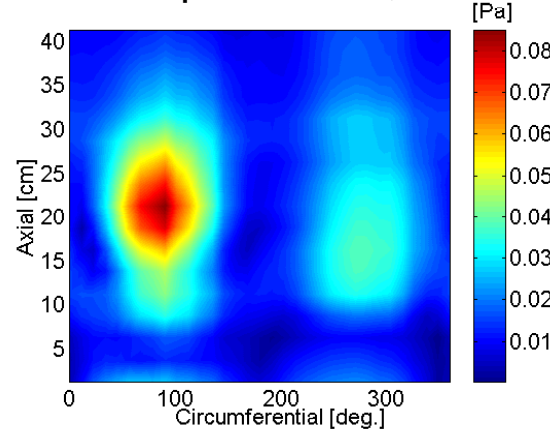
Total field, Level I



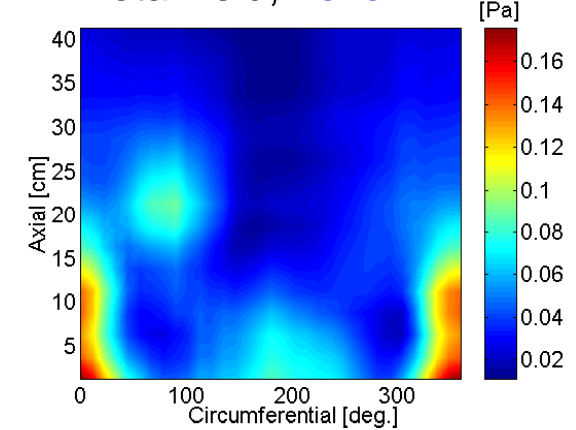
First partial field, Level II



Second partial field, Level II



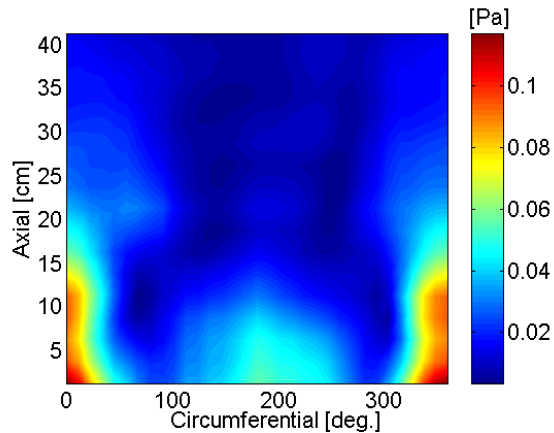
Total field, Level II



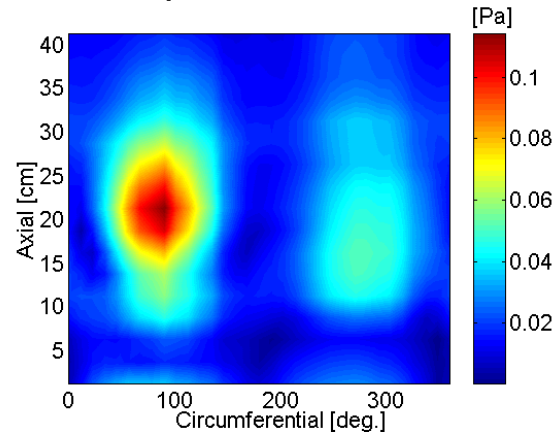
# LOUDSPEAKER MEASUREMENT

Estimated sound fields from source level I (based on source level II  $H_{yr}$ )

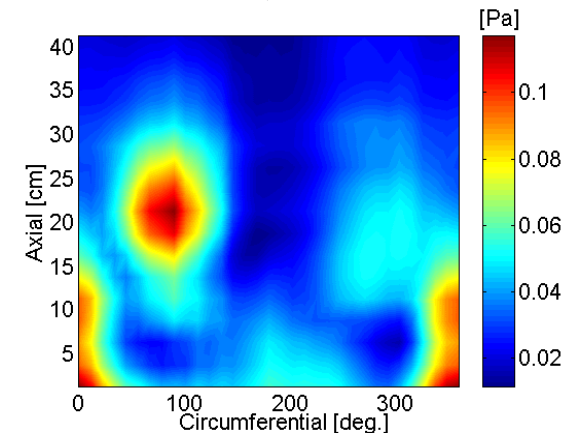
First partial field, ref. 1 & 2



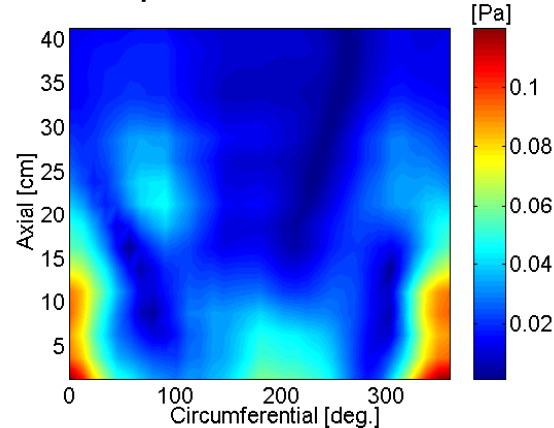
Second partial field, ref. 1 & 2



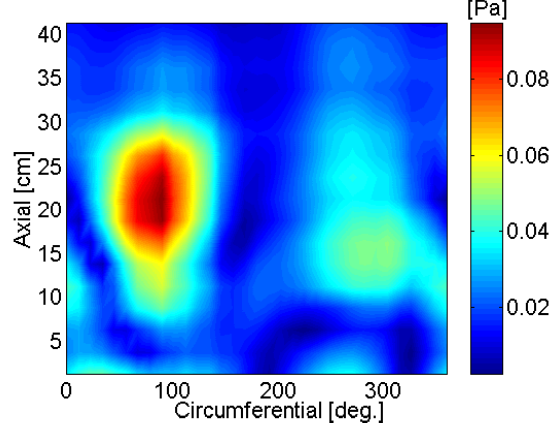
Total field, ref. 1 & 2



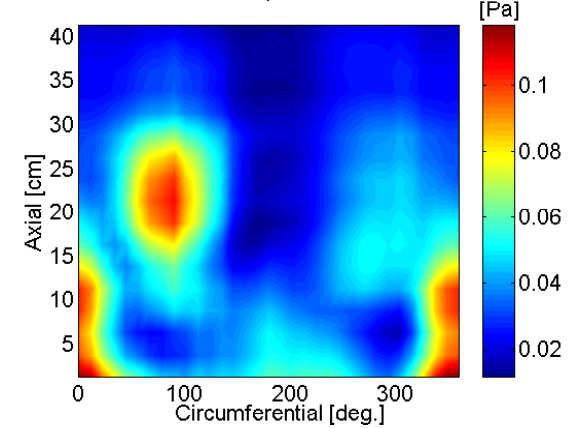
First partial field, ref. 3 & 4



Second partial field, ref. 3 & 4



Total field, ref. 3 & 4





# CONCLUSIONS

- Once the transfer functions between the reference and field microphones were found, entire sound field for any operating condition could be reconstructed based on **reference measurements** alone.
- Accurate total fields were obtained even when the reference microphones were placed an unrealistically large distance from the sources and even when partial fields included contribution from both sources.
- This approach can facilitate more detailed investigation of acoustic sources in various operating conditions.
- Potential quality control application to check the total radiated sound fields of many “similar” devices based on reference measurements.